1. Scope

1.1 This procedure covers requirements for special-quality alloy steel forgings for through hardened gears. It meets or exceeds material requirements for through hardened gears in accordance with grade 2 of ANSI/AGMA 2101, grade MQ of ISO 6336-5, and grade II of ANSI/AGMA 6033.

1.2 This procedure applies to disk or pancake forgings, forged rings, cylindrical forgings (solid or hollow), and barstock.

2. Referenced Documents

2.1 ANSI/AGMA 2101 Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth.

2.2 ANSI/AGMA 6033 Materials for Marine Propulsion Gearing.

2.3 ISO 6336-5 Calculation of Load Capacity of Spur and Helical Gears- Part 5: Strength and Quality of Materials.

2.4 ASTM E 112 Test Methods for Determining Average Grain Size.

2.5 ASTM A 255 Test Method for End-Quench Test for Hardenability of Steel.

2.6 ASTM A 290 Standard Specification for Carbon and Alloy Steel Forgings for Reduction Gears.

2.7 ASTM A 304 Standard Specification for Carbon and Alloy Steel Bars Subject to End-Quench Hardenability requirements.

2.8 ASTM E 381 Method of Macroetch Testing, Inspection, and Rating Steel Products, Comprising Bars, Billets, Blooms, and Forgings.

2.9 ASTM A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings.

2.10 ASTM E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection.

2.11 ASTM A 534 Standard Specification for Carburizing Steels for Anti-Friction Bearings.

2.12 ASTM A 866 Standard Specification for Medium Carbon Anti-Friction Bearing Steel.

3. Ordering Information

3.1 Information- Orders shall include quantity, alloy grade, dimensions, and tolerances of forgings.

4. Manufacture

4.1 Melting practice

4.1.1 Material shall be manufactured by electric-furnace, ladle refined, deoxidized, vacuum-degassed process.

4.1.2 Ingots shall be bottom poured big-end-up. Material shall be protected from reoxidation during teeming.

4.1.3 Continuous casting processes shall not be used.

4.2 Discard- Sufficient discard shall be made from the top and bottom of each ingot to ensure freedom from piping and undue segregation.

4.3 Forging reduction ratio- Forgings shall be brought as close as practical to finished shape and size by hot mechanical work adequate to work the steel uniformly throughout its section. Reduction ratio shall be at least 3:1 for forgings and at least 5:1 for barstock.

4.3.1 After forging and before reheating for heat treatment, forgings shall be cooled in a manner that prevents flakes and segregation.

4.4 Machining- Before heat treatment, forgings shall be machined to remove at least 3 mm material from all surfaces.

4.5 Heat Treatment

4.5.1 Normalize- All forgings shall be normalized at 925 °C ± 10 °C for a minimum of ½ hour per 25 mm of maximum section thickness or two hours, whichever is greater. Forgings shall be removed from the furnace and cooled under uniform conditions in still air.

4.5.2 Quench and temper- All forgings shall be quenched and tempered to meet hardness requirements specified on the engineering drawing for the gear.

5. Chemical Requirements

5.1 Heat analysis- Each heat of steel shall be analyzed by the manufacturer to determine percentages of elements. Analysis shall be done on a test sample taken during pouring of the heat. Chemical composition thus determined shall conform to requirements of ASTM A 290 except silicon, aluminum, phosphorus, sulfur, calcium, oxygen, and hydrogen shall conform to the requirements of this specification.

5.1.1 Silicon content- The steel shall be deoxidized and fully killed with silicon.

5.1.2 Aluminum content- A minimum amount of aluminum shall be used and restricted to the amount necessary to control grain size. Total aluminum content shall not exceed 0.035%.

5.1.3 Phosphorus content- Total phosphorus content shall not exceed 0.025%.

5.1.4 Sulfur content- Total sulfur content shall not exceed 0.025%.

5.1.5 Calcium content- Calcium shall not be added unless specifically approved by purchaser. If calcium is added, it shall not be detectable by chemical analysis.

5.1.6 Oxygen content- Total oxygen content shall not exceed 20 ppm.

5.1.7 Hydrogen content- Total hydrogen content shall not exceed 2.0 ppm.

6. Quality Tests

6.1 The supplier shall be responsible for the quality of material furnished and shall make the necessary tests to ensure this quality.

6.2 Ultrasonic inspection- Ultrasonic inspection shall be made at the manufacturer's plant on all forgings in accordance with ASTM A 388/A 388M. Straight-beam examination using either the reference-block or the back-reflection technique shall be used.

6.2.1 Forged rings- Scan entire rim section from circumference and both faces.

6.2.2 Cylindrical forgings (solid or hollow) and barstock- Scan entire circumference from outside diameter to mid-radius.

6.2.3 Disc or pancake forgings- Scan radially from circumference through entire rim or tooth section to 50 mm below roots of teeth, and from both faces.

6.3 Ultrasonic quality levels- The following acceptance criteria shall apply in accordance with the inspection technique used.

6.3.1 Back-reflection technique

6.3.1.1 No indications larger than 15% of the first back reflection.

6.3.1.2 No indications equal to 15% of the first back reflection and less than 13 mm apart as determined by transducer movement.

6.3.1.3 No areas showing loss of back reflection larger than 40% of the first back reflection.

6.3.1.4 No traveling indications larger than 10% of the first back reflection and longer than 19 mm as determined by transducer movement.

6.3.2 Reference-block technique- A reference block 8-0400 with 3.2 mm flat-bottom hole in accordance with ASTM E 428 shall be used. A distance amplitude correction curve shall not be used.

6.3.2.1 No indications equal to or larger than the indication received from the flat-bottom hole of the reference block.

6.3.2.2 No indications equal to or larger than 50% of the indication received from the flat-bottom hole of the reference block if accompanied by 50% loss of back reflection.

6.3.2.3 No indications that are continuous over an area twice the diameter of the search unit.

6.4 Grain size- Each heat shall be tested for grain size in accordance with ASTM E 112. At least 70% of the grains shall be size number 5 to 8.

6.5 Hardenability- Each heat shall be tested for hardenability by Jominy end-quench tests in accordance with ASTM A 255. Hardenability shall be in the upper half of the "H" band and shall meet the requirements of ASTM A 304.

6.6 Macroetch and Cleanliness- Each heat shall be tested for macroetch and inclusion rating in accordance with ASTM A 866. Macroetch rating shall not exceed S2, R2, and C2 of Method E 381. Inclusion rating shall not exceed the rating specified in Table 1.

Table 1- ASTM A 866 Inclusion Rating	
Thin Series	Heavy Series
A 2.5	A 1.5
B 2.0	B 1.0
C 1.0	C 1.0
D 1.5	D 1.0

6.7 Banding- Each heat shall be tested for microstructural banding in accordance with ASTM A 534. Banding shall meet the requirements of ASTM A 534 S5.

7. Mechanical Properties

7.1.1 Test specimens- Number, location, and orientation of test specimens shall be in accordance with ASTM A 290.

7.1.2 Test requirements- The steel shall be tested for hardness, tensile properties, and impact properties in accordance with ASTM A 290.

7.1.3 Acceptance criteria- Hardness, tensile properties, and impact properties shall meet the requirements of Table 3 of ASTM A 290 for the class corresponding to the hardness specified on the engineering drawing for the gear.

8. Microstructural Properties

8.1.1 Test specimens- Number, location, and orientation of test specimens shall be in accordance with ANSI/AGMA 6033.

8.1.2 Test requirements- Microstructural properties shall be determined by metallographic examination in accordance with ANSI/AGMA 6033.

8.1.3 Acceptance criteria- Microstructure shall consist primarily of tempered martensite. Maximum percent of secondary transformation products such as proeutectoid ferrite, upper bainite, and fine pearlite shall not exceed the limits specified in Table 2.

Table 2- Microstructural Requirements	
Maximum controlling section (mm)	Maximum secondary transformation products (%)
< 125	5
125 - 250	10
> 250	20

9. Workmanship

9.1 Forgings shall conform to sizes and shapes specified by the purchaser, shall be free from injurious defects such as cracks, tears, bursts, seams, and laps, and shall have a workmanlike finish.

10. Product Marking

10.1 Identification marks shall be legibly stamped on each forging and each test specimen. Each heat shall be identified and bundled separately for shipping.

11. Inspection

11.1 The manufacturer shall provide the purchaser's representative all reasonable facilities necessary to ensure that product is furnished in accordance with this specification.

12. Certification and Reports

12.1 The manufacturer shall supply certified documentation that product was manufactured and tested in accordance with this specification. Documentation shall be traceable to the heat and forging, and include results from all tests as follows:

12.1.1 Description of melting practice,

12.1.2 Forging reduction ratio,

12.1.3 Records of heat treatment including furnace time and temperature,

12.1.4 Chemical composition,

12.1.5 Oxygen and hydrogen content,

12.1.6 Ultrasonic certification,

12.1.7 Grain size,

12.1.8 Hardenability,

12.1.9 ASTM A 866 certification including macroetch and inclusion rating,

12.1.10 ASTM A 534 S5 certification including hardness variation,

12.1.11 Mechanical properties, and

12.1.12 Microstructural properties.